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Cross-Layer Interaction for IP Centric Video Applications in MIMO Broadband Wireless Networks

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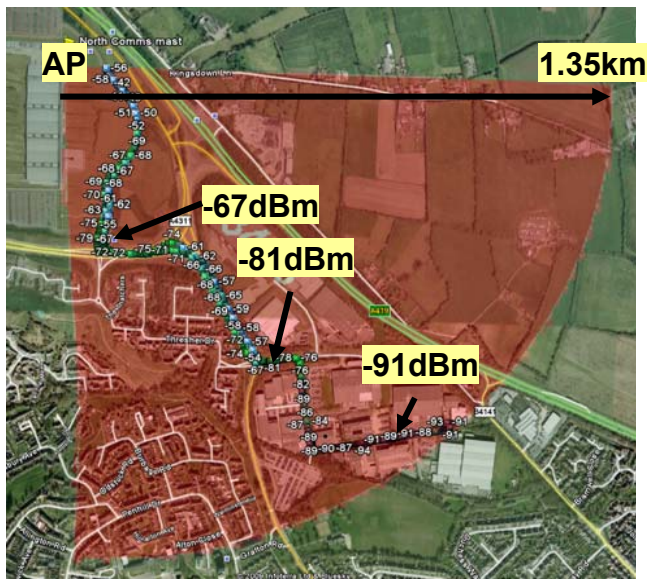
Introduction

- SISO mobile WiMAX benchmark.
- MIMO summary.
- MIMO vs. SISO measurement comparison.
- WiMAX simulator validation and EBF extension.
- Exploiting EBF in next generation IP-centric user applications using intelligent scheduling.

SISO WiMAX Benchmark

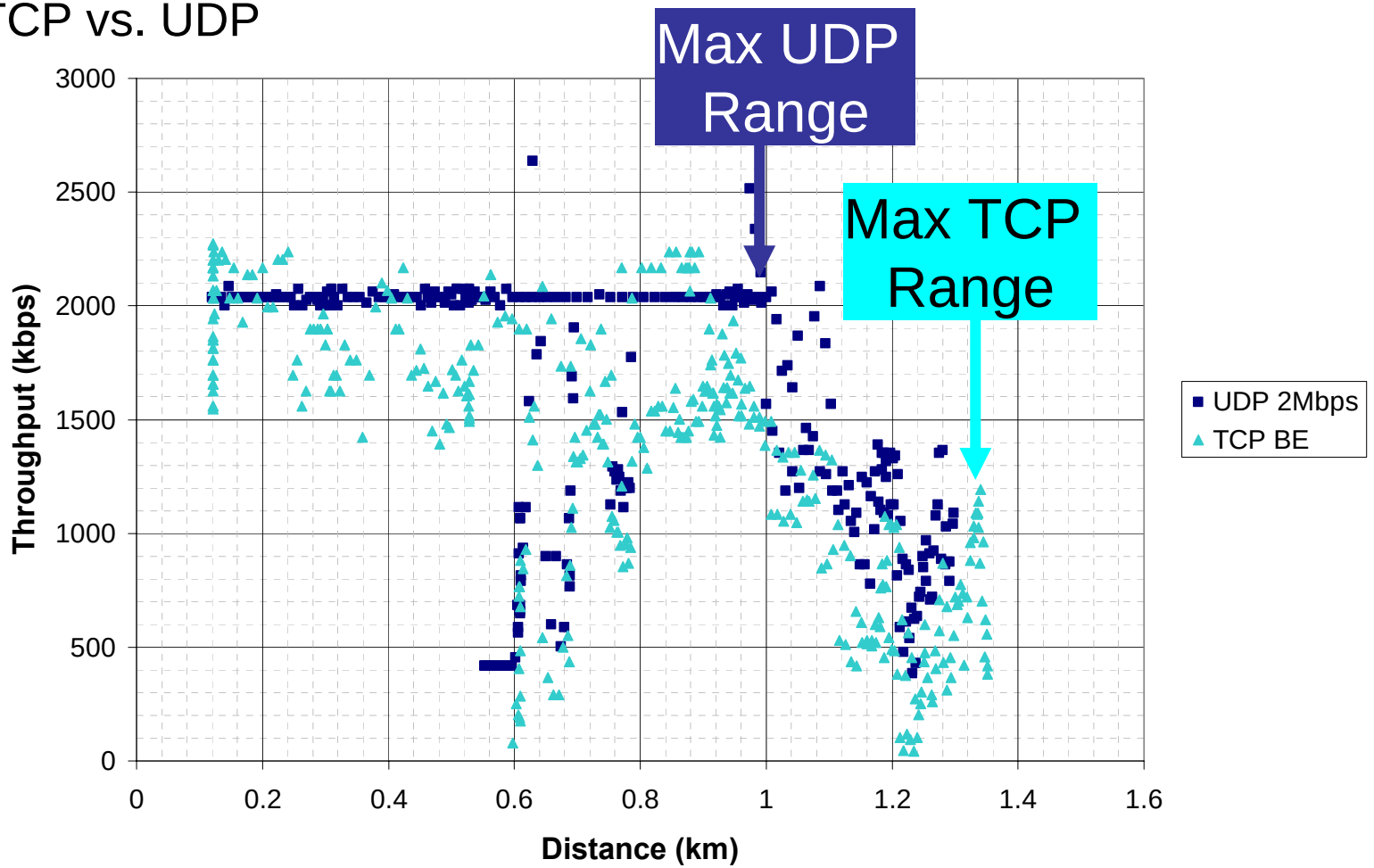
- Single 90^{o} sector, 46.5dBm EIRP, 3.5GHz, 5MHz bandwidth.
- Maximum range 1.35km.
- 2Mbps UDP video reached only 1km, Best Effort (BE) TCP operates up to cell edge.



RSSI plot for high power single sector WiMAX system

WiFi vs. WiMAX (2)

- TCP vs. UDP



Application throughput vs. distance for WiMAX system

MIMO

- MIMO Techniques
  - STBC (Space Time Block Coding)
  - SM (Spatial Multiplexing) MMSE
  - EBF (Eigen-beamforming)
- EBF with water-filling – maximises capacity.
- EBF requires large overheads due to feed-back.
- Statistical EBF with short-term selection reduces feed-back
  - Feeds back only a pre-selected set of eigen-vectors (long-term) and the appropriate eigen-vector index (short-term).
- This study uses a 4x1 Statistical EBF implementation
  - Average weights for bands of subcarriers are computed using an iterative method equivalent to SVD.

WiMAX Measurements

32x2 mile round trips!

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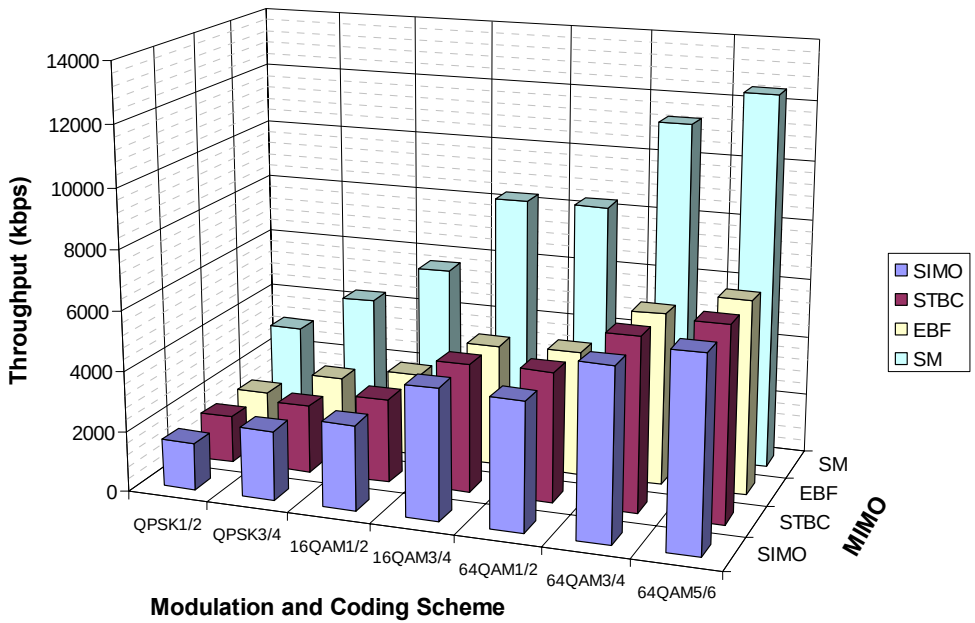
Measured WiMAX MIMO vs. SIMO

- MIMO vs. SIMO measurements
  - STBC and EBF have throughputs equal to SIMO.
  - SM has 2 x throughput, up to 12.5Mbps in 64QAM 5/6.
  - SM usage using Automatic MIMO Selection (AMS) very dependent on antenna configuration, 81% achieved using Dual Slants at both ends.



Maximum throughput for each MCS and MIMO scheme

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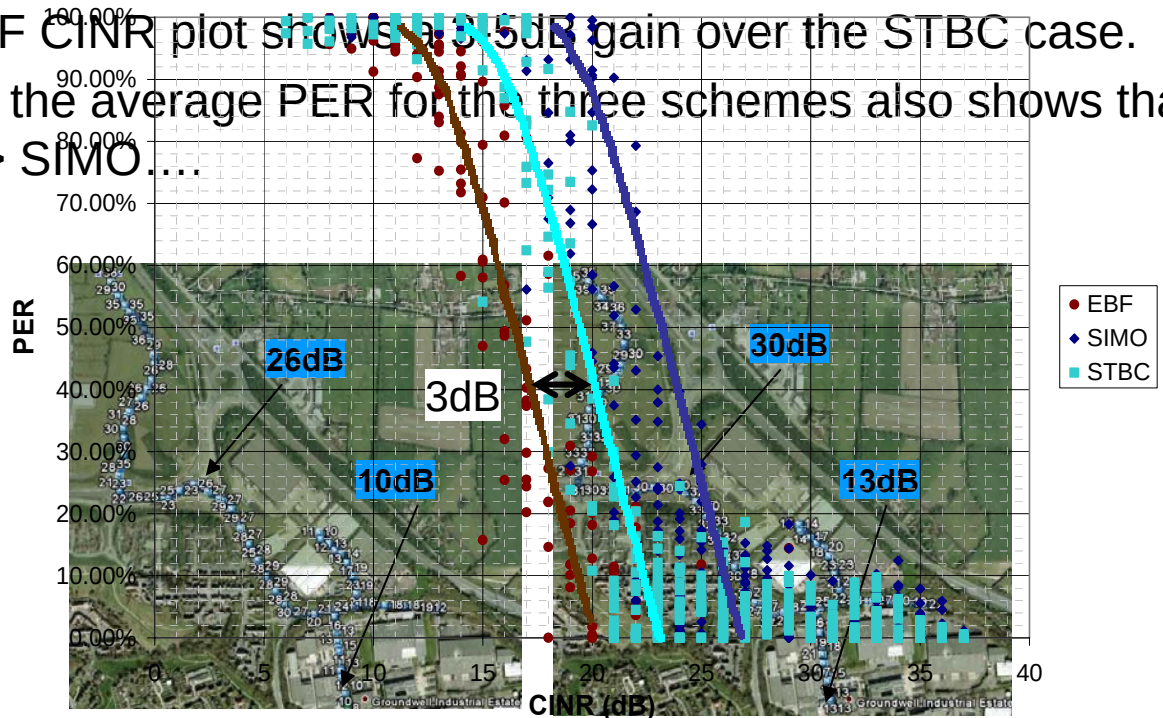
Measured WiMAX MIMO vs. SIMO (2)

- MIMO vs. SIMO measurements
  - Packet Error Rate (PER) graph shows that 2x2 STBC and 4x1 EBF (both diversity order 4) outperform 1x2 SIMO (diversity order 2).
  - EBF outperforms STBC due to array gains, theoretically by up to 6dB.
  - The EBF CINR plot shows a 3-5dB gain over the STBC case.
  - Plotting the average PER for the three schemes also shows that EBF > STBC > SIMO….



STBC CINR plot. **EBF CINR plot.**

PER for SIMO, STBC and EBF for 64QAM 2/3 mode.

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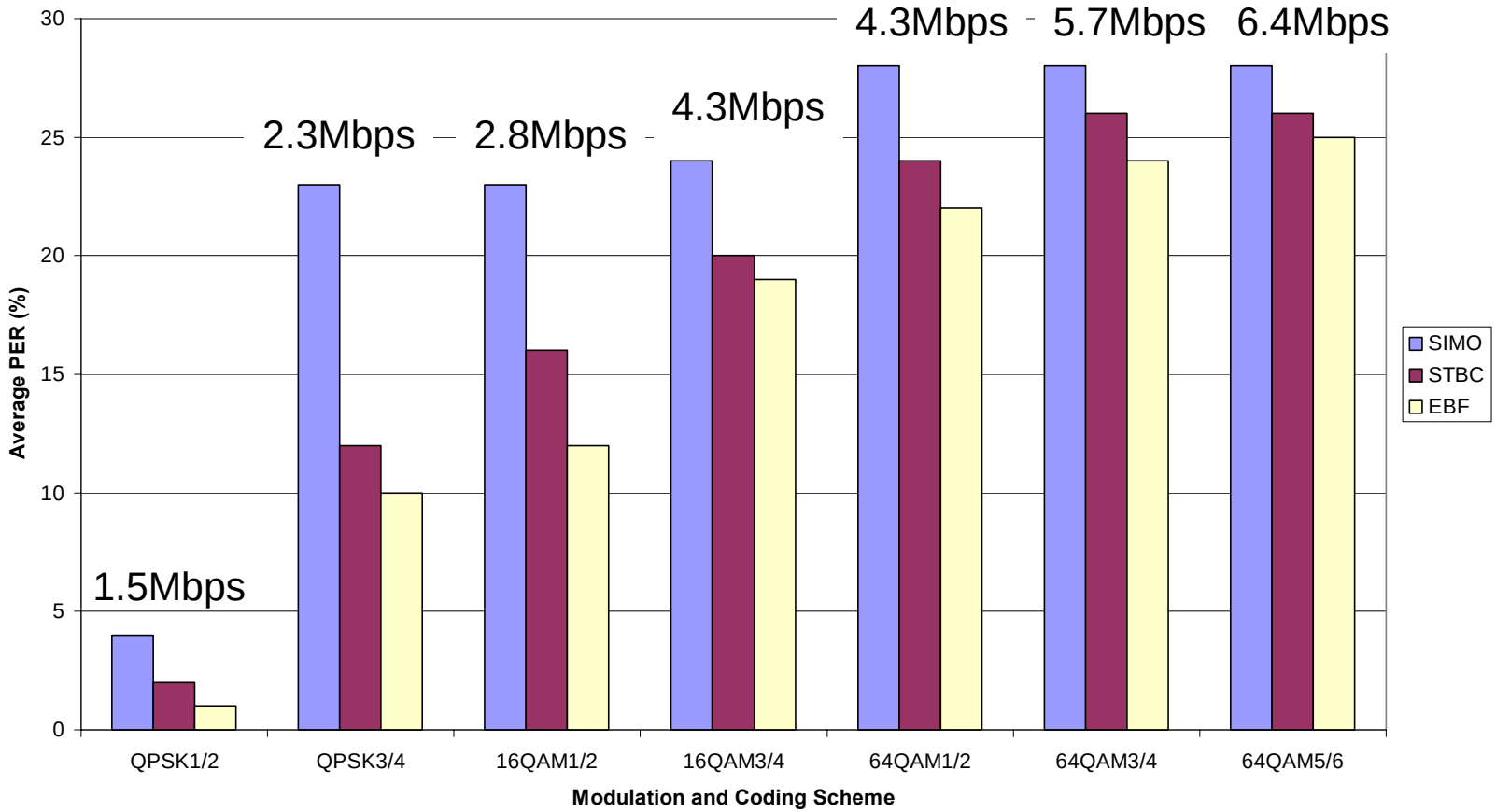
Measured WiMAX MIMO vs. SIMO (3)

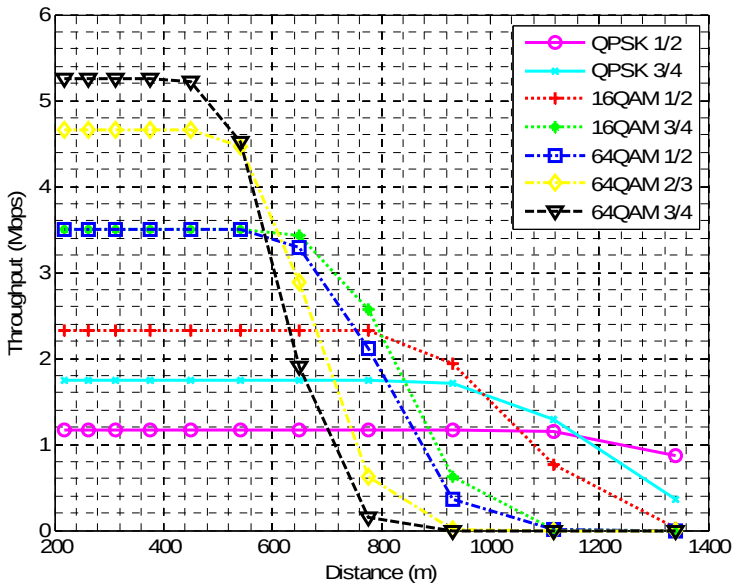
- Average raw PHY PER for SIMO, STBC and EBF



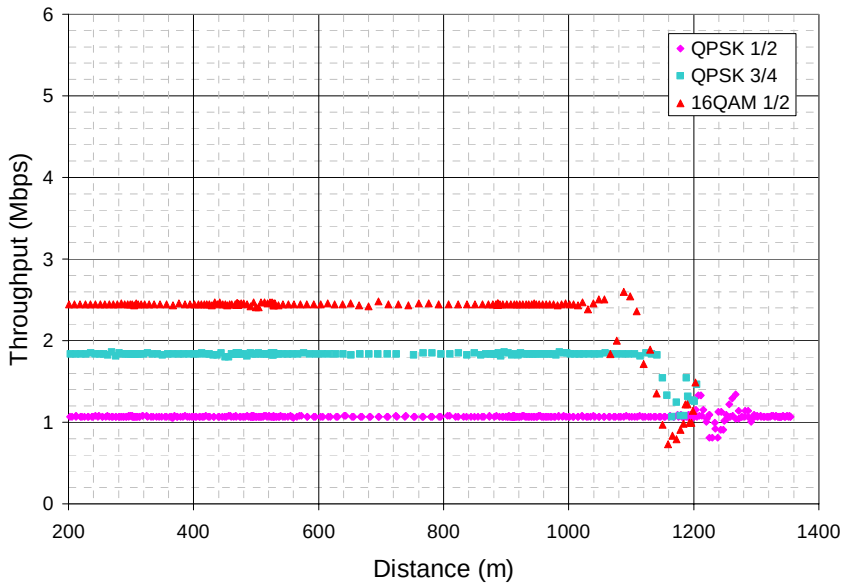
Average PER for SIMO, STBC and EBF for each MCS.

WiMAX Simulator Validation

- All simulated Physical Layer (PHY) throughputs within 5% of those measured.
- Measured and simulated distances show close correlation.



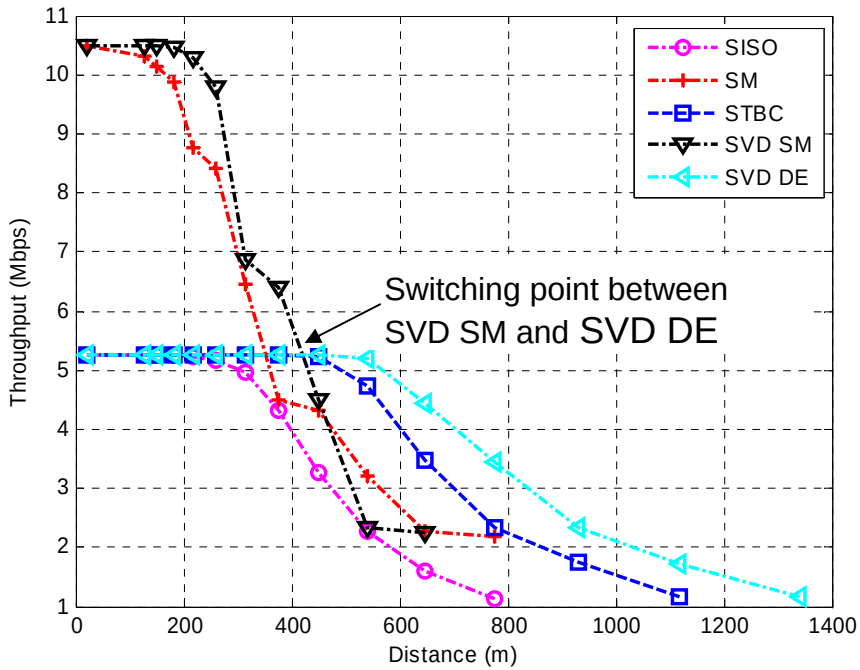
Simulated tput vs. distance (2x2 STBC).



Measured tput vs. distance (2x2 STBC).

WiMAX Simulator (3)

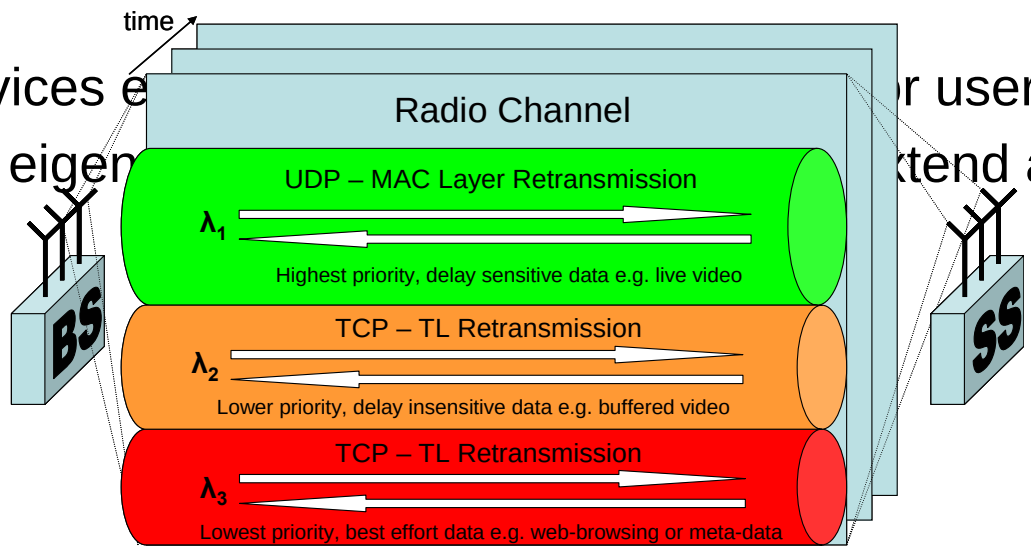
- Implementation of SM Eigen-beamforming extension
  - Uses Singular Value Decomposition (SVD).
  - Limited to maximum 10% PER to reflect application performance.
  - Compared SISO, SM MMSE, STBC, SM EBF (SVD SM) and dominant EBF (SVD DE).
  - SM EBF optimum < 420m (>19dB).
  - Dominant EBF optimum > 420m.
  - SVD increases the range from 780m in the single case and 1120m in the STBC case to 1340m.
  - Leads to very simple AMS strategy;
    - At high SNRs SM EBF is used to improve throughput.
    - At low SNRs dominant EBF is used to improve robustness.



Simulated max tput vs. distance for MIMO modes.

Eigen-beamforming Applications

- Scalar channels resulting from EBF are of varying power and quality.
- This disparity can be exploited to enhance multimedia - send higher priority data on the stronger eigen-channels and vice versa.
- Combination of intelligent channel-dependent scheduling and MIMO allows for optimisation between MAC, PHY, transport and application layers.
- Different services e… …r user experience.
- Use unequal eigen… …xtend and equalise ranges.



Intelligent scheduling with eigen-beamforming and 3x3 MIMO

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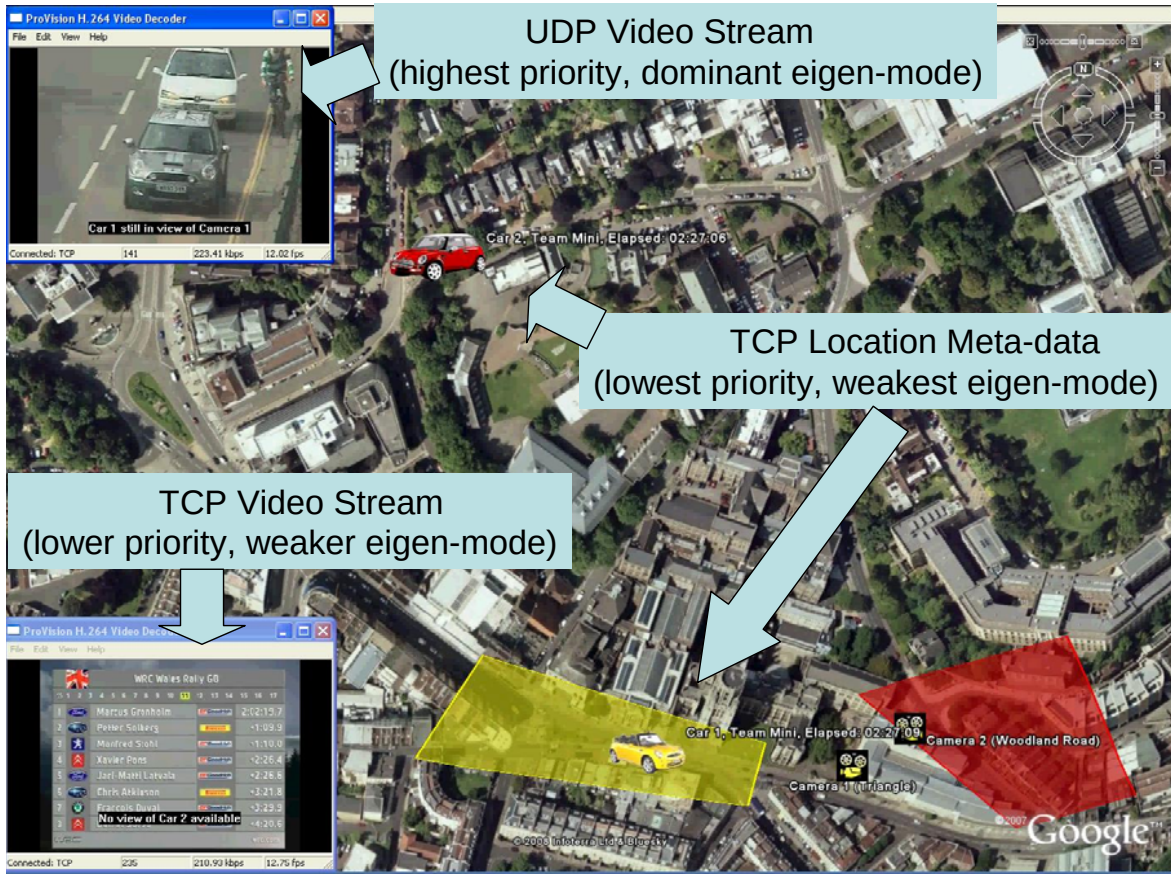
Eigen-beamforming Applications (2)

- Next generation IP-centric user application



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Summary

- Real-world MIMO mobile WiMAX data collected and used to validate simulator.
- Advanced simulation shows EBF can give twice throughput at close range and extend range by 50%.
- Used intelligent scheduling to prioritise the allocation of services to suitable eigen-channels
- Unequal power distribution extends and equalises the service ranges.
- Combined this cross-layer interaction with EBF to create a novel, resource efficient, personalised user application.

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Any Questions?

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MIMO Extra

- EBF (Eigen-beamforming)
  - The channel impulse response experienced by the *i*th subcarrier is given by; $H^{i}{}_{M\times N} = \left\lfloor H^{i}{}_{m,n} \right\rfloor_{M\times N}$
  - Where *M* and *N* are the number of receive and transmit antennas.
  - Using SVD this gives; $H^{i}_{M\times N} = U_{M\times M} S_{M\times N} V^{H}_{N\times N}$
  - *U* and *V* are unitary, singular vectors and *H* indicates the Hermitian process. *S* contains the eigen-values of the channel.
  - Pre-processing the transmitted signal using *V* and post-processing it using *U'* yields;

$$U^{H}_{M\times N} U_{M\times N} S_{M\times N} V^{H}_{M\times N} V_{M\times N} = I \cdot S_{M\times N} \cdot I = S_{M\times N}$$

MIMO Extra (2)

- EBF with Water-filling
  - Fills to a common level using; $\frac{1}{\lambda_1}+P_1=\frac{1}{\lambda_2}+P_2=\frac{1}{\lambda_3}+P_3=\ldots=D$
  - Where the following power constraint applies; $\sum P_i = P$
  - This increases the SISO capacity – $C=\log_2(1+P)$

  to $C=\sum_N \log_2(1+\lambda_i P_i)=\sum_N \log_2(\lambda_i D)$
- Statistical EBF with short-term selection.
  - The decomposition of the expectation of the covariance matrix is given by; $R_{\tilde{H}_i}=E\left[\tilde{H}_i^H(t)\tilde{H}_i(t)\right]=E_i\Lambda_i E_k^H$
  - Where i=0,1,2..,S-1.